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What Do Emissions Markets Deliver and to Whom? Evidence from Southern California's NO_x Trading Program†

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An advantage of cap-and-trade programs over more prescriptive environmental regulation is that compliance flexibility and cost effectiveness can make more stringent emissions reductions politically feasible. However, when markets (versus regulators) determine where emissions occur, it becomes more difficult to assure that mandated emissions reductions are equitably achieved. We investigate these issues in the context of Southern California's RECLAIM program by matching facilities in RECLAIM with similar California facilities also in nonattainment areas. Our results indicate that average emissions fell 20 percent at RECLAIM facilities relative to our counterfactual. Furthermore, observed changes in emissions do not vary significantly with neighborhood demographic characteristics. (*JEL* H23, L51, Q53, Q58)

Policymakers have a variety of instruments at their disposal when pursuing emissions reduction objectives. Traditionally, regulators have relied upon "command-and-control" (CAC) approaches involving prescriptive emissions limits or pollution control technology standards. Increasingly, however, emissions trading programs are the preferred policy choice. In the United States, the Clean Air Act Amendments (CAAAs) of 1990 initiated a monumental shift away from CAC regulation towards more market-based alternatives such as emissions trading.[1] In parts of Europe, New Zealand, and regions of the United States, greenhouse gas regulations have helped to bring so-called "cap and trade" to the fore.

Despite this prominence, questions remain about how emissions trading is working in practice. First, can these market-based programs reduce emissions beyond

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[1] The CAAAs authorized the use of economic incentive regulation for the control of acid rain, the development of cleaner burning gasoline, the reduction of toxic air emissions, and for states to use in controlling carbon monoxide and urban ozone.

what could be achieved with more prescriptive CAC regulation? A perceived advantage of market-based approaches over CAC is that they can, in some circumstances, deliver more significant public health and environmental benefits because lower compliance costs and greater compliance flexibility make more stringent emissions reductions politically feasible (US EPA 1992; Keohane, Revesz, and Stavins 1998; Ellerman 2006; Tietenberg 2006). Although this hypothesis seems plausible, it has been difficult to test empirically (Stavins 1998; Ellerman 2004; Harrington and Morgenstern 2007).

Second, some have expressed concern that a reliance on permit markets (versus prescriptive regulations and standards) to coordinate pollution abatement activity can lead to environmental injustice (Solomon and Lee 2000; Vandenbergh and Ackerly 2007; Kaswan 2008).[2] If polluting facilities can achieve compliance by purchasing permits versus reducing emissions, there is the possibility that permitted pollution will flow into areas where poor or minority populations live. As detailed below, these environmental justice concerns are fueling heated opposition to emissions trading at the state and federal level.[3]

We examine these two issues in the context of a renowned emissions market: the REgional CLean Air Incentives Market (RECLAIM). Our primary objective is to identify the causal effects of this emissions trading program on facility-level emissions vis-à-vis the CAC regulations it replaced. Our essential challenge is to construct a credible benchmark, a precise and believable estimate of the emissions we would have observed in the absence of the program. Design features unique to RECLAIM facilitate the construction of this counterfactual. More specifically, we can exploit the fact that only a subset of industrial facilities located in nonattainment counties in California were removed from a CAC regime and required to participate in RECLAIM.

The RECLAIM program marked many firsts for emissions trading. It was the first mandatory trading program to supplant a preexisting CAC regime that was, in theory, capable of achieving the same environmental objectives. It was the first program to include a broad and diverse population of sources, making it particularly relevant to future trading programs which are likely to be more heterogeneous to achieve increasingly aggressive air quality and climate goals.[4] Illaudably, it was also the first emissions trading program to be challenged on the grounds of environmental injustice and noncompliance.

Our analysis of the RECLAIM program is motivated by three observations. First, a recent resurgence of interest in RECLAIM makes our study both timely and appropriate. Cap-and-trade programs have figured prominently in regional and federal proposals for addressing climate change, thus drawing increased attention to past experiences with market-based instruments in general, and RECLAIM in particular. Recent attempts to extract constructive insights from the RECLAIM experience have arrived at very different conclusions. Whereas some regard the

[2] Although a broad literature examines environmental justice concerns with respect to plant siting, CAC regulation, and neighborhood location choices (see, for example, Banzhaf and Walsh 2008), few papers assess the environmental justice effects of emissions trading.

[3] Among environmental justice advocates, concerns about greenhouse gas emissions trading pertain to copollutants. Whereas greenhouse gases are a global pollutant (damages do not depend on the spatial location of the source), copollutants, and associated damages, can be local.

[4] For example, under the auspices of Assembly Bill 32, California is preparing to implement a greenhouse gas emissions trading program that covers large industrial sources of greenhouse gas emissions.

program as a clear success (Stavins 2008), others see a "spectacular" failure (Green, Hayward, and Hassett 2007).[5]

Second, axiomatic questions about the effectiveness in reducing pollution of market-based programs relative to more traditional CAC regulations remain controversial and unresolved. Compared to the previous literature addressing these questions (see, for example, Harrington and Morgenstern 2007), we take a fundamentally different approach.[6] We exploit the participation requirements of the RECLAIM program in order to construct semiparametric estimates of program impacts. Emissions trajectories at RECLAIM facilities are compared with those at similar California facilities that are exempt from RECLAIM. One important advantage of this approach is that it mitigates—or eliminates—the potentially confounding effects of changing economic conditions at the state level, industrywide production trends, and technological change.

Finally, our empirical framework facilitates an analysis of how RECLAIM-induced changes in emissions are distributed across communities with different socioeconomic characteristics. For a number of reasons, the RECLAIM market has been the most criticized of any emissions trading program with respect to environmental justice concerns. Some contend that RECLAIM has placed a disproportionate burden of the region's air pollution in low-income, minority communities (Drury et al. 1999; Moore 2004; Lejano and Hirose 2005). We combine semiparametric matching methods with parametric regression techniques. This allows us to examine correlations between RECLAIM-induced emissions changes and socioeconomic neighborhood characteristics with unprecedented precision.

Our results indicate that emissions at RECLAIM facilities have fallen by approximately 20 percent, on average, relative to control facilities (i.e., similar California facilities that remained subject to command-and-control regulation over the duration of the study period). These results are robust to alternative estimation methods, functional form specifications, and different control group composition. Furthermore, we fail to reject the hypothesis that pollution reductions under RECLAIM were equally distributed across neighborhoods with different socioeconomic characteristics.

The paper proceeds as follows. Section I provides background on Southern California's RECLAIM program, emphasizing past experiences with program evaluation and environmental justice issues in particular. Section II describes the research design and econometric approach. Section III summarizes the data. Section IV presents the empirical findings. Section V concludes.

[5] Stavins (2008) summarizes domestic experience with emissions trading and reports that the RECLAIM program has generated significant environmental benefits "with NO_x emissions in the regulated area falling by 60 percent." Green, Hayward, and Hassett (2007) discuss the relative strengths and weaknesses of greenhouse gas emissions trading relative to a carbon tax. While reflecting upon past experiences with the former approach, they note that: "additional pitfalls and dilemmas of emissions trading can be seen through a review of the spectacular trading failure of the RECLAIM." They go on to argue that although "SCAQMD estimated that SO_2 and NO_x would be reduced by fourteen and eighty tons per day, respectively, … RECLAIM never came close to operating as predicted."

[6] Both Stavins (1998) and Ellerman (2004) note that, in the context of comprehensive cap-and-trade programs such as the Acid Rain Program, it has been difficult (if not impossible) to construct credible estimates of the emissions that would have been observed under a different regulatory regime. Harrington et al. (2004) compare outcomes from controlling similar pollutants in the United States and Europe using different policy instruments. The limitation of this approach is that differences in outcomes across the two contexts likely reflect social, cultural, political, and economic differences, in addition to differences in regulatory regimes.

I. Background on RECLAIM

In this section, we introduce Southern California's RECLAIM program and provide some background on two areas of emphasis: the measurement of the emissions impacts of RECLAIM and related environmental justice concerns.

A. *A Brief History of the Regional Clean Air Incentives Market*

Los Angeles suffers from some of the worst air quality in the nation.[7] The South Coast Air Quality Management District (SCAQMD) is the government agency responsible for regulating air pollution in the Los Angeles basin. In 1989, SCAQMD introduced an aggressive set of rules and standards for stationary sources. Industry representatives fiercely opposed these rules on the grounds that compliance costs would prove excessive.

In 1990, Congress turned its attention to the widespread failure of US cities to attain health-based national ambient air quality standards (NAAQS). Under the 1990 CAAAs, federal NO_x standards were significantly revised. Because SCAQMD was much further from attainment compared to other air basins, the district was given more time to comply. Although required reductions in ozone concentration levels were larger for the Los Angeles basin compared to other nonattainment areas in California, the required rates of concentration reductions over time were quite similar.[8]

The CAAAs also provided general authorization for states to use market-based regulatory programs to achieve federal standards. Market-based approaches to pollution regulation were endorsed on the grounds that CAC approaches were insufficient to address the worst of the nation's air quality problems, and that market-based approaches offered a "historic opportunity to help reconcile the nation's economic and environmental aspirations" (US EPA 1992). While the use of economic incentives to achieve air quality standards was discretionary in most cases, it was required in extreme nonattainment areas, e.g., Los Angeles.[9]

SCAQMD responded by replacing over 40 prescriptive rules, which had been so opposed by industry, with a market-based emissions trading program: RECLAIM.[10] This program was approved by state and federal regulators on the grounds that it would deliver emissions reductions equivalent to—or greater than—what would have been achieved under the subsumed command-and-control provisions, and would help to bring the region into compliance with federal standards by the 2010 deadline.

[7] Air pollution problems are due in part to meteorological and topographical conditions; the basin is sunny, warm, and poorly ventilated. The dense population, large number of vehicles, and high levels of industrial activity also contribute significantly to the problem. In 1988, ozone levels in the Los Angeles air basin exceeded state standards on 148 days (California Air Resources Board air quality data statistics accessed May 15, 2008. http://www.arb.ca.gov/adam/php_files/aqdphp/sc8start.php). Prior to the introduction of RECLAIM, estimates of health-related losses due to the poor environmental quality in the region were approaching $10 billion per year (Hall et al. 1992).

[8] Section IVC characterizes the CAAA compliance requirements in more detail.

[9] Pursuant to Sections 182 and 187, the US Environmental Protection Agency (EPA) issued a final rule and guidance on Economic Incentive Programs (40, part 51, Subpart U) which outlined requirements for establishing EIPs. States or governing bodies in extreme ozone nonattainment areas were required to design and implement economic incentive programs (51.492, 182(g)5).

[10] Although both NO_x and SO_2 emissions are capped under the program, the emphasis was on limiting NO_x emissions, which are an important precursor to ozone formation.

At its inception in 1994, RECLAIM included 392 facilities whose combined NO_x emissions accounted for over 65 percent of the region's stationary NO_x emissions (Zerlauth and Schubert 1999). Almost all facilities in the SCAQMD with annual NO_x or SO_2 emissions of four tons or more are included in the program.[11] Public facilities (such as police and firefighting facilities) were categorically excluded. Sources emitting less than four tons per year remained subject to command-and-control programs.

A RECLAIM trading credit (RTC) confers the right to emit one pound of emissions within a 12-month period. At the outset of the program, facilities were informed of how many permits they would be allocated gratis each year through 2010.[12] These RTCs were distributed based on firms' historical fuel consumption and predetermined production technology characteristics.[13] Figure 1 plots the aggregate allocation trajectory over time (the solid line).[14] NO_x emissions permitted under RECLAIM were reduced by over 70 percent over the first ten years of the program. By the end of 2003, the aggregate permit allocation reached the level of emissions that the subsumed rules and control measures were intended to achieve by 2010.

Early on, most firms found they had an excess of credits (the dashed line in Figure 1 represents aggregate tons of NO_x emissions). The aggregate cap did not start to bind until 1999 (SCAQMD 2001). Figure 1 helps to illustrate this "crossover" point. While it is clear that emissions permits were initially overallocated, many believe that generous permit allocations in the early years of the program were necessary to engender political support for the program (US EPA 2002).[15] Because permits cannot be banked, impacts of the initial overallocation were confined to the early stages of RECLAIM.

Figure 1 also plots the trend in average RTC prices (the dotted line). In the first five years of the program, prices for NO_x RTCs remained relatively low, as expected.[16] However, the increase in prices following the crossover was much larger than anticipated; the price of NO_x RTCs increased from approximately \$2,000 per ton in January of 2000 to over \$120,000 per ton in March of 2001.

During the California electricity crisis, production levels at electricity generating facilities in the RECLAIM program increased significantly. Emissions at these

[11] Of these, 73 percent can be classified as manufacturing firms, 13 percent are involved in communication, transportation, or utilities, 2 percent are involved in construction, 3 percent are operating in the service sector, 6 percent in wholesale trade, 2 percent are retail establishments, and the remaining 3 percent can be classified as government facilities.

[12] RTCs cannot be banked; a permit can be used to certify only emissions occurring within the 12-month period with which the permit is associated. For emissions in any quarter, firms can use permits expiring either in June or in December. See Holland and Moore (forthcoming).

[13] The RTC allocation methodology is described in detail in SCAQMD Rule 2002 (http://www.aqmd.gov/rules/siprules/sr2002.pdf).

[14] Section III includes a detailed description of these data.

[15] Nonetheless, RECLAIM may have changed firms' production and investment decisions in this early period. A firm making a long-lived investment may have abated early in anticipation of higher future prices. Furthermore, RECLAIM relaxed a vintage differentiated regulation, New Source Review, that has limited firms' abilities to modify facilities. For example, only Best Available Control Technology (BACT) is required, and necessary offsets can be demonstrated with RTCs. RECLAIM annual reports show a very high rate of NSR activity. From 1994 to 2006, the reports show that on average 47 RECLAIM facilities had NSR activity per year. In contrast, the Committee on Changes in New Source Review Programs for Stationary Sources of Air Pollution (2006) reports that on average 125 NSR permits per year were issued for the entire country from 1997 to 2002 for NO_x.

[16] Before RECLAIM began, it was predicted that trading in the market would be slow at first because of the initial surplus of permits. In 1994, SCAQMD economists predicted that prices for NO_x RTCs would average around \$577/ton in 1995 and rise to approximately \$1,100/ton by 1999 (Miller, Michael. 1994. "Firms Can Earn Credits for Keeping Emissions Down, Then Sell Them." *The San Francisco Examiner.* January 9, 1994: B1).

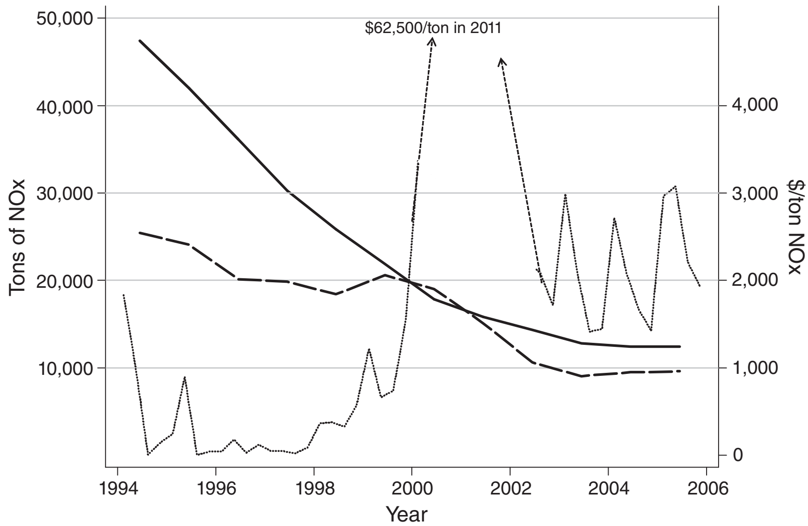

Figure 1

Note: Trends in nitrogen oxides emissions (dashed), allocations (solid), and permit price (dotted).

facilities exceeded permit allocations, which in turn led to a sharp increase in RTC prices.[17] In May 2001, the RECLAIM rules were amended in an effort to stabilize the RTC market. The rule amendments (Rule 2009) removed 14 power producers from the RECLAIM market. These facilities were required to pay a fee of $15,000 per ton of emissions in excess of their allocation. They were also required to install the "best available" control technologies on existing power generating units by the end of 2004.[18] In 2007, these large power producers reentered the RECLAIM program as unrestricted market participants.

By 2002, monthly average prices had fallen below $2,000 per ton NO_x. Regulators were concerned that low permit prices were failing to provide sufficient incentives for facilities to install pollution control technologies that would be needed to bring the region into compliance with federal standards. In September of 2004, restrictions on power producers were made more stringent, and the aggregate RTC allocation for compliance years 2007–2011 was reduced by an additional 20 percent.

B. *RECLAIM Program Evaluation*

Because RECLAIM represented such a major departure from the traditional regulatory approach, both federal and state agencies required extensive program evaluation and oversight. Emissions trading program evaluation is particularly challenging. Because industrial emissions are influenced by numerous factors, attributing changes in emissions patterns to specific policy interventions is difficult. These

[17] Kolstad and Wolak (2003) provide evidence that some electricity producers in SCAQMD intentionally purchased NO_x RTCs at higher than competitive prices so as to be able to artificially increase electricity prices.

[18] For more information, see SCAQMD (2007).

challenges notwithstanding, agencies in charge of overseeing RECLAIM remain committed to evaluating the emissions impacts of the program.

Unresolved disagreements about what constitutes an appropriate measure of counterfactual emissions have resulted in a plurality of opinions regarding RECLAIM's overall performance. After 15 years of program evaluations, the emissions impacts of RECLAIM vis-à-vis the subsumed CAC rules remain controversial. Federal policymakers and other stakeholders have expressed frustration over the lack of consensus emerging from RECLAIM program evaluations, noting that the public is entitled to "real world information and practical comparisons in order to judge for itself whether the program is living up to their needs and expectations" (US EPA 2002). Online Appendix A summarizes some of the contradictory evidence provided by past program evaluations and reports.

C. Environmental Justice and Emissions Trading

The term "environmental injustice" refers to any disproportionate human health or environmental impact on minority or low-income populations.[19] Empirical research conducted in the 1980s demonstrated significantly higher levels of exposure to environmental hazards in traditionally disadvantaged communities.[20] Subsequent work has brought more sophisticated empirical methods to bear on this issue (Banzhaf and Walsh 2008).

Kaswan (2008) provides a detailed discussion of the perceived tensions between environmental justice and emissions trading. A dominant concern is that emissions trading programs fail to account for the distribution of pollution damages, whereas permitting under the CAAAs can explicitly consider environmental justice concerns. If polluting facilities can purchase permits instead of reducing emissions, it is possible for permitted pollution to flow into areas where poor or minority populations live, thereby exacerbating preexisting inequalities in the distribution of environmental risks. On the other hand, market-based programs could mitigate preexisting environmental justice problems. If polluting facilities with relatively low marginal abatement costs are disproportionately located in traditionally disadvantaged neighborhoods, an efficient permit market should ensure that a larger share of the mandated emissions reductions will be achieved in these areas (Burtraw et al. 2005).[21]

For a number of reasons, the RECLAIM market has been the most scrutinized of any emissions trading program with respect to environmental justice issues (Chinn 1999; Drury et al. 1999; Moore 2004; Lejano and Hirose 2005). First, the Los Angeles area is home to an exceptionally diverse population. Past studies have documented that race and ethnicity have historically played a "persistent explanatory role" in the distribution of environmental health risks in Southern California (Morello-Frosch, Pastor, and Sadd 2001). Second, NO_x is a nonuniformly mixed pollutant. This means that there is potential for significant spatial variation in damages from NO_x emissions, and

[19] Executive Order No. 12,898, 3 C.F.R. (1995) *Reprinted as Amended* in 42 U.S.C. §4321 (1994 and Supp. IV 1998).

[20] See, for example, GAO (1983), United Church of Christ (1987), and Brown (1995).

[21] Past studies looking at the distributional impacts of emissions trading have looked closely at the Acid Rain Program. These studies find no evidence of disproportionately high and adverse human health or environmental effects on minority, low-income, or other populations (EPA 2005; Shadbegian, Gray, and Morgan 2007).

thus potential for environmental injustice.[22] Third, the RECLAIM program was indirectly implicated in another highly controversial rule promulgated by SCAQMD that allowed stationary sources to offset their uncontrolled emissions of volatile organic compounds (VOCs) using mobile source emissions reduction credits.[23] Although the links between RECLAIM and this controversial rule were indirect, the RECLAIM program has since been associated with environmental injustice allegations.[24]

Concerns about environmental justice have strongly influenced the debate surrounding California's greenhouse gas regulations (Hanemann 2008; Sze et al. 2009). Regulatory activities in California under A.B. 32 constitute the most ambitious and comprehensive effort to control GHG emissions currently under way in the United States. Prominent environmental justice advocates have come out in strong opposition to cap and trade in California due to concerns about mercury, benzene, and other copollutants. They cite RECLAIM as a "well documented" example of how emissions trading can disproportionately harm communities of color (Drury 2009).[25] Citizens groups filing a lawsuit in 2011 to prevent greenhouse gas emissions trading in California alleged that "All the evidence show(s) that cap-and-trade programs have failed environmental justice communities" (Sweet 2011).

II. Research Design

Previous estimates of the emissions effects of RECLAIM are conditional on, and highly sensitive to, controversial assumptions about what emissions would have been in the absence of the program. In this study, we exploit some unique design features of the RECLAIM program in order to construct more tenable and transparent estimates of counterfactual emissions. Rather than rely on ex ante expectations about what aggregate emissions trajectories would have been absent RECLAIM, we use econometrically adjusted ex post observed emissions at facilities that were subject to CAC regulation over the same time period. In what follows, we introduce our empirical framework and identification strategy.

A. *Empirical Framework*

Building on the potential outcome framework that is now standard in the program evaluation literature, we postulate that there are two regulatory states to which California's industrial NO_x emitters could have been assigned: the market-based

[22] In the interest of avoiding "hotspots," RECLAIM was designed as a zonal trading system. The SCAQMD was divided into two zones: the region along the coast, and an inland region. Facilities along the coast (where pollution problems tend to be more severe) may purchase RTCs only from other coastal facilities. Inland facilities can purchase permits from either inland or coastal facilities.

[23] Environmental justice groups challenged this rule as violating the Civil Rights Act by allowing reductions in mobile source emissions to be substituted for VOC reductions at point sources located in minority communities. The lawsuit was withdrawn by the plaintiffs. See "CBE Sues SCAQMD Over Amendments to Car Scrapping Rule," *California Environmental Insider*: 12 (7), September 15, 1998. In 2003, a second lawsuit alleged RECLAIM violated the Clean Air Act. SCAQMD agreed to establish a million-dollar fund to reduce emissions in environmental justice communities in the Los Angeles area. See *Our Children's Earth*, News Release, March 23, 2004.

[24] The RECLAIM program, as it was originally designed, permitted the use of mobile source credits to achieve compliance. This mobile source credit compliance option was rarely used. Mobile source credits represented less than 0.02 percent of the total allocation of NO_x permits.

[25] See online Appendix C for a more detailed discussion of these arguments.

RECLAIM program or the CAC regime that prevails in nonattainment counties outside of SCAQMD (and which the SCAQMD continues to use to regulate smaller emitters). Let $D_i = 1$ if the ith facility is included in RECLAIM (i.e., the facility is "treated"). Let $D_i = 0$ if facility i remains subject to CAC regulation throughout the duration of our study. Potential outcomes $Y_{it}(1)$ and $Y_{it}(0)$ denote annual emissions at facility i at time t conditional on participation and nonparticipation, respectively.

We are primarily interested in estimating the sample average treatment effect on the treated (SATT):

$$\alpha_{TT} = E[Y_{it'}(1) - Y_{it'}(0) \mid D_i = 1], \tag{1}$$

where t' represents a year following the introduction of the RECLAIM program and α_{TT} measures the average effect of the RECLAIM program on annual facility level NO_x emissions.[26]

Emissions at both treated and untreated facilities are observed prior to the RECLAIM program (i.e., when all facilities in California's nonattainment areas were subject to CAC regulation) and over several years following the introduction of the program. Facility-level emissions data collected from RECLAIM participants during years following the introduction of the program can be used to identify $E[Y_{it'}(1) \mid D_i = 1]$. However, $[Y_{it'}(0) \mid D_i = 1]$ is not observed. We will construct estimates of these counterfactual outcomes using emissions observed at control facilities subject to CAC regulation for the duration of the time period.

Incomplete program participation requirements provide us with two potential comparison groups. First, the RECLAIM program applies only to major sources located within SCAQMD. Thousands of California facilities located outside the Los Angeles air basin are subject to more traditional CAC. Second, hundreds of smaller emitters within SCAQMD remain subject to more traditional CAC rules.

The simplest and most naive estimate of α_{TT} is obtained by computing an unconditional difference-in-differences. This estimator will be biased if factors that are related to facility-level emissions dynamics vary significantly across the treatment and comparison groups. In order to reduce the bias potentially introduced by observable differences across RECLAIM participants and nonparticipants, we employ two strategies that condition on observable covariates.

Regression-Based Conditioning Strategies.—Ordinary least squares (OLS) can be used to control for factors other than regulatory regime that affect facility-level emissions trajectories. We estimate the following simple specification:

$$Y_{it'} - Y_{it^0} = \boldsymbol{\beta}'\mathbf{X}_i + \alpha D_i + \varepsilon_i, \tag{2}$$

where $\mathbf{X}_i$ is a vector of observable covariates and t^0 denotes the time period prior to the introduction of RECLAIM. This approach implicitly assumes that the variables in $\mathbf{X}$ are exogenous to treatment status. In our case, these variables will include facility-level emissions before RECLAIM was introduced, four-digit industry

[26] We will also evaluate program impacts in percentage terms, although we will emphasize (1) as a more informative measure of the average effect of RECLAIM on industry emissions.

classification, county-level attainment status, and pretreatment, facility specific economic and demographic measures. The parameter α captures the average effect of the RECLAIM program on changes in facility-level emissions over time conditional on variables in $\mathbf{X}$. The error term ε_i is assumed to be independent of the covariates in $\mathbf{X}_i$ and the treatment indicator D_i.

There are several potential problems with this approach. First, if there is only limited overlap in the distributions of $\mathbf{X}$ across the treatment and control groups and functional form assumptions are incorrect, missing outcomes will be incorrectly imputed. Estimates of average treatment effects can also be biased if control observations are not appropriately reweighted to control for differences in the distribution of the $\mathbf{X}$ variables over regions common to the control and treatment groups. In the interest of mitigating these potential biases, we turn to semiparametric matching estimators.

Semiparametric Conditioning Strategies.—Matching estimators are an extension of standard regression approaches. One clear advantage is that parametric assumptions about the relationship between the outcome variable and the covariates in $\mathbf{X}$ can be avoided. Our general approach to matching follows Heckman, Ichimura, and Todd (1997) and Heckman et al. (1998) who introduce the following generalized DID matching estimator:

$$(3) \qquad \widehat{\alpha_{DID}} = \frac{1}{N_1} \sum_{j \in \mathcal{I}_1} \Big\{ \big(Y_{jt'}(1) - Y_{jt^0}(0)\big) - \sum_{k \in \mathcal{I}_0} w_{jk} \big(Y_{kt'}(0) - Y_{kt^0}(0)\big) \Big\}.$$

Here, $\mathcal{I}_1$ denotes the set of program participants, $\mathcal{I}_0$ denotes the set of nonparticipants, and N_1 is the number of facilities in the treatment group. The participants are indexed by j; the nonparticipants are indexed by k. The weight placed on facility k when constructing the counterfactual estimate for treated facility j is w_{jk}. Our nearest neighbor matching estimator weights control facilities according to their similarity to treated facilities where similarity is based on $\mathbf{X}$.

B. *Identifying Assumptions*

Our most important identifying assumption is that the biases in the unconditional DID estimates can be removed by adjusting for differences in observable covariates. More formally, we assume that the distribution of the control outcome $Y_{it'}(0)$, conditional on observable facility and neighborhood characteristics (such as historic emissions, industry classification, county attainment status), is the same among participating and nonparticipating facilities. If this conditional unconfoundedness assumption is satisfied, once we adjust for observable differences, we can interpret differences in observed outcomes as the effect of RECLAIM versus the CAC regimes of other California air basins.

In our context, we also invoke a stronger variant of the unconfoundedness assumption. In order to interpret (3) as an estimate of the effect of RECLAIM on emissions vis-à-vis what would have been observed under the status quo, it must be that trends in the stringency of the control treatment (i.e., the CAC regulations to which the control facilities are subjected) follow the trajectory that the SCAQMD CAC regime would have taken absent RECLAIM.

Our estimation strategy also requires that the support of the distribution of the conditioning covariates in the treatment group overlaps the support of the distribution of these covariates in the comparison group.

Finally, in order to rule out spillovers and general equilibrium effects, it must also be the case that potential outcomes at one facility are independent of the treatment status of other facilities. We refer to this subsequently as the stable unit treatment value assumption (SUTVA).

Some of these assumptions can be directly tested. For instance, it is straightforward to demonstrate that the overlap condition is satisfied by simply looking at the joint distributions of the covariates in the treated and control groups. Other assumptions, including unconfoundedness and SUTVA, are not testable in principle. However, we will conduct indirect tests in order to evaluate the plausibility of these assumptions.

C. *Treatment Effect Heterogeneity*

Thus far, we have been exclusively concerned with estimating the average effect of RECLAIM on facility-level emissions. We are also interested in investigating whether treatment effects vary systematically across facilities located in neighborhoods with different socioeconomic characteristics. We estimate the following weighted regression:

$$Y_{it'} - Y_{it^0} = \delta_j + \boldsymbol{\beta}'\mathbf{X}_i + \boldsymbol{\theta}'\mathbf{X}_i D_i + \alpha D_i + \varepsilon_i, \tag{4}$$

where the δ_j are group-specific fixed effects and group j comprises treated facility j and its m_j closest matches. What distinguishes this approach from more standard regression-based strategies is that observations are weighted as in matching. To investigate the extent to which emissions trading has exacerbated (or mitigated) environmental injustice vis-à-vis CAC regulations, socioeconomic and demographic variables are included in $\mathbf{X}_i$.

III. Data

About 10,000 polluting facilities in California report annual emissions of criteria pollutants to the California Air Resources Board (ARB). All polluting facilities are required to report to their local Air Quality Management District. The ARB maintains a database of emissions reports from these local districts (ARB 1987–2005). Our primary data come from this database, which also includes information on industry classification. We use addresses, geocodes, and industry classifications to ensure a consistent coding of facilities across our panel.[27] We also use separate emissions data from RECLAIM to verify the emissions reported to the ARB database (SCAQMD 2007).

[27] To ensure consistent coding over time, we identify facilities with different IDs but the same address and SIC. If the facilities do not report emissions in more than one overlapping year, then we code the facilities with the same ID. To ensure consistent coding within a year, we combine facilities with different IDs but the same geocodes and SIC.

We obtain demographics data from 1990 and 2000 Censuses at the block group level.[28] The data include median household income, in 1989 and in 1999, and population by ethnicity and race. We construct a measure of percent minority as the percent of the population that is either non-Hispanic black or Hispanic.[29] To account for the possibility that households can sort based on pollution exposure, we emphasize the 1990 data, versus the more recent 2000 data that may be endogenous to emissions due to sorting (Banzhaf and Walsh 2008).

To prepare these demographics data for use in our analysis, we construct radii of differing lengths surrounding each facility. We determine the percent of a block group's geographic area that is within a half, one, and two miles of each facility and use these percentages to characterize the neighborhood surrounding each facility. For example, for the one-mile radius, we calculate the percent of each block group that is within a mile of a facility. We multiply that percentage by the corresponding census block group populations (separately for each demographic group). We then aggregate over block groups to get the total number of affected individuals for that facility. We replicate this procedure for a half-, one-, and two-mile radius, and for each population subgroup. Note that this assumes a uniform geographic distribution of population within a block group.

Trends in Facility-Level NO_x Emissions.—Figure 2 shows the declining trends in total NO_x emissions at California facilities between 1990 and 2005. The figure illustrates that, in the aggregate, NO_x emissions from both facilities in RECLAIM and those in comparison groups were declining at similar percentages prior to the introduction of RECLAIM. In the early years of the RECLAIM program (i.e., when the aggregate cap was not binding) emissions of RECLAIM facilities appear to increase slightly relative to facilities outside the program. After the cross-over point in 2000, however, the average rate of emissions decrease among RECLAIM facilities exceeds that of non-RECLAIM facilities. Overall, emissions among RECLAIM facilities have dropped 72 percent relative to pre-1993 levels, whereas emissions among nonparticipating facilities have dropped only 62 percent over the same period.

Table 1 summarizes a balanced sample of these same data. To construct this table, the data are partitioned into four nonoverlapping periods. Period 1 encompasses years prior to the introduction of the RECLAIM program (i.e., 1990–1993). Period 2 covers the early years of the RECLAIM program when the emissions cap exceeded aggregate emissions (1997–1998). Period 3 includes years immediately following the "cross-over" point (2001–2002). Period 4 includes the most recent years (2004–2005). The sample includes all facilities reporting positive emissions in each period. Period 1 annual facility-level emissions are similar between RECLAIM facilities and the comparison group. Average emissions among RECLAIM facilities

[28] US Census Bureau, 1990 and 2000. Demographic data is summarized in the online Appendix Table A1.

[29] Figure A1 helps to illustrate the spatial distribution of this measure. This figure was generated using zip code–level demographics data. In the econometric analysis we use more disaggregated (i.e., census block) data which should be less susceptible to aggregation issues such as the ecological fallacy and the modifiable areal unit problem.

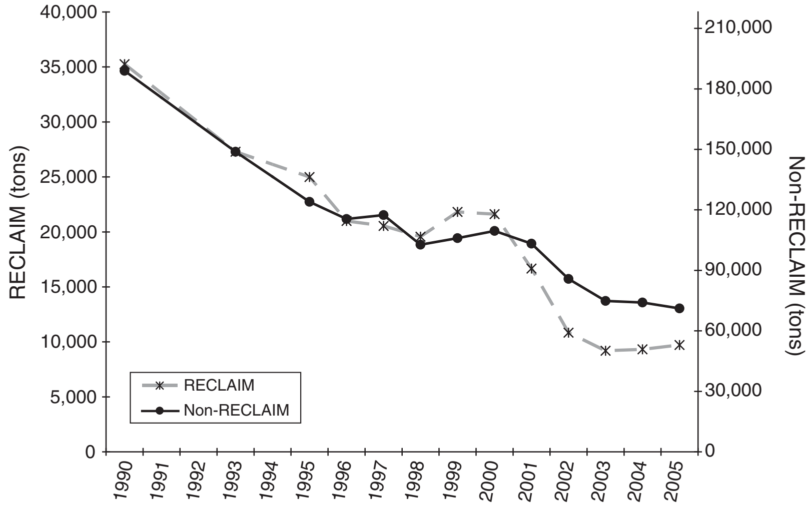

Figure 2. Total NO_x Emissions in RECLAIM and in the Rest of California

Table 1—Summary Statistics of NO_x Emissions

Period	RECLAIM	Control	Total
Period 1	101.8	102.8	102.6
(1990–1993)	(304.4)	(430.5)	(411.9)
Period 2	62.7	80.0	77.1
(1997–1998)	(179.8)	(371.0)	(346.3)
Period 3	43.8	67.9	63.8
(2001–2002)	(125.4)	(339.6)	(314.0)
Period 4	30.8	53.0	49.2
(2004–2005)	(117.1)	(290.8)	(269.6)

Notes: We report the summary statistics on the balanced sample of facilities with positive emissions in all four periods. We include the 13 RECLAIM facilities temporarily removed from the program. We report the mean tons of NO_x emissions per facility (e.g., 101.8) as well as the standard deviation (304.4). There are 213 facilities in RECLAIM and 1,052 in the control group. The control group is restricted to facilities in the same two-digit SIC codes as RECLAIM facilities and that were located in counties that, during 1990 and 1993, were not in attainment with the one-hour ozone National Ambient Air Quality Standards.

fell 70 percent between period 1 and period 4.[30] This table also illustrates the control group's annual emissions fell approximately 50 percent.

The full panel of facility-level data is unbalanced. Between periods 1 and 4, 32 percent of RECLAIM facilities and close to 54 percent of non-RECLAIM facilities fail to report emissions in one or more years. Facility-level emissions data in a given period may be missing for a number of reasons, including errors in the data, a facility's failure to report emissions in a given period, or the exit of a facility. On average, treated

[30] When the sample omits the 14 power producers removed from RECLAIM in period 3, average emissions fell from 72.2 to 31.5 (a similar percentage reduction).

Table 2—Summary Statistics for Major Industries

		Treatment			Control			
Industry	RECLAIM share	Obs	Mean	SD	Obs	Mean	SD	95 percentile overlap
Petroleum refining	37.5%	10	880	978	18	988	1,570	1
Electric services	23.9%	21	378	408	85	393	981	1
Crude petroleum/natural gas	7.1%	10	116	124	191	68	190	1
Cement	4.1%	2	699	909	9	1,885	951	1
Glass containers	3.8%	1	611		5	856	341	1
Natural gas trans. and distribution	2.3%	8	85	83	4	474	612	0.88
Paper mills	1.8%	6	82	166	5	121	170	0.83
Electric and other services combined	1.6%	4	107	83	65	330	854	1
Industrial inorganic chemicals	0.9%	5	31	30	10	223	683	1
Steel works, blast furnaces	0.9%	3	103	120	4	20	36	0.66
Steam and air-conditioning supply	0.9%	7	39	37	2	55	55	0.57
Products of petroleum and coal, NEC	0.8%	1	260		1	580		1
Total for major industries	87%	78	288	498	399	282	768	0.96

Notes: "RECLAIM share" is the four-digit SIC industry share of initial, period 1 NO_x emissions. We report summary statistics of tons of facility-level NO_x emissions during period 1 for both treated and the control facilities. The final column reports the proportion of the treatment group that falls within the 2.5th and 97.5th percentiles of the empirical distribution of period 1 NO_x emissions in the corresponding SIC code class of controls.

facilities reporting emissions in all periods were larger emitters in period 1, although not significantly so.[31] Section IVE discusses sample selection issues in more detail.

Industrial Composition of the Treatment and Control Groups.—Table 2 examines the distributions of historic, facility-level NO_x emissions among treated and control facilities, respectively. We focus on the 12 industries which accounted for the largest shares of NO_x emissions in period 1. While refining and electricity generation are the largest polluters, about 40 percent of emissions are from firms in other four-digit SIC codes. The final column of this table reports the proportion of RECLAIM facilities with historic emissions within the 2.5th and 97.5th percentiles of the empirical distribution of historic emissions among control facilities in the same industry. In most cases, the support of the distribution of emissions in RECLAIM is completely overlapped by the support of the distribution in the control group. These summary statistics help to highlight a limitation of our matching strategy. Ideally, we would like to match each treated facility with a large number of control facilities in the same industry to average out idiosyncratic shocks in our estimate of counterfactual emissions. However, in some industries, the number of control facilities with very similar historic emissions will be limited. This could have implications for match quality. We revisit this issue below.

[31] Among RECLAIM participants, average period 1 emissions are 101.8 tons and 95.0 tons for "balanced" facilities (i.e., those facilities reporting emissions in all four periods) and unbalanced facilities, respectively. For this sample, a simple regression of emissions on an indicator variable of being in the balanced sample has a standard error of 35.3 tons. Among the control group, these averages are 102.8 tons and 57.5 tons, respectively. These are statistically different as the standard error of this sample is 13.3.

Table 3—Change in Emissions (*tons*) Weighted by Demographic Group from the 1990 Census

	Actual change			Relative change		
Group	0.5 miles	1 mile	2 miles	0.5 miles	1 mile	2 miles
White, low income	−23.5***	−56.0**	−58.4***	−8.7**	−12.9**	−14.0***
	(7.4)	(22.1)	(17.6)	(3.4)	(5.7)	(5.3)
White, middle income	−94.9**	−69.6***	−64.6***	−37.2*	−24.1**	−19.3**
	(42.7)	(21.0)	(21.3)	(19.6)	(10.1)	(8.4)
White, high income	−170.3**	−163.5***	−135.3***	−58.5***	−53.5***	−38.9***
	(68.4)	(56.0)	(44.1)	(21.9)	(18.7)	(13.9)
Black, low income	−14.5***	−16.9***	−29.8***	−2.9	−3.6	−11.7**
	(5.3)	(5.1)	(10.2)	(2.5)	(2.5)	(5.7)
Black, middle income	−48.8**	−47.2**	−43.0*	−19.3*	−17.3	−16.0
	(20.7)	(22.2)	(22.5)	(10.9)	(11.9)	(12.5)
Black, high income	−110.0	−108.3	−67.8*	−55.4	−53.5	−25.8
	(74.7)	(71)	(36.4)	(41.7)	(39.7)	(20.3)
Asian, low income	−16.2***	−23.1**	−29.7***	−4.4	−5.4	−9.0*
	(5.7)	(8.8)	(8.7)	(2.8)	(5.3)	(5.1)
Asian, middle income	−36.7***	−38.8***	−46.8**	−13.9***	−12.2**	−13.9*
	(9.5)	(11.5)	(21.3)	(5.2)	(5.9)	(8.4)
Asian, high income	−131.9**	−116.6**	−95.6**	−62.6*	−42.2**	−28.4**
	(55.7)	(45.4)	(39.8)	(34.0)	(17.7)	(14.2)
Hispanic, low income	−20.3***	−28.5***	−33.8***	−4.3*	−6.7	−10.8
	(5.7)	(9.1)	(12.4)	(2.4)	(5.2)	(7.6)
Hispanic, middle income	−35.3***	−34.3***	−33.8***	−12.0***	−7.1	−8.6*
	(10.7)	(10.0)	(8.5)	(3.6)	(4.8)	(4.6)
Hispanic, high income	−108.9***	−90.9***	−66.7***	−48.1**	−35.1***	−19.0***
	(35.6)	(25.5)	(17.6)	(19.8)	(11.0)	(6.9)
All whites	−109.8***	−105.6***	−94.5***	−39.5***	−33.8***	−26.9***
	(35.4)	(30.6)	(27.3)	(13.1)	(10.9)	(9.0)
All blacks	−37.8**	−36.3**	−37.8**	−15.2	−13.5	−14.5
	(16.9)	(15.8)	(15.7)	(9.3)	(8.7)	(8.8)
All Asians	−55.2***	−53.9***	−56.2***	−23.7**	−17.8**	−16.8**
	(17.4)	(16.1)	(20.3)	(10.3)	(6.9)	(7.8)
All Hispanics	−31.3***	−34.6***	−36.3***	−9.8***	−8.8*	−10.9*
	(6.9)	(7.9)	(10.0)	(2.9)	(4.5)	(6.1)
All low income	−19.9***	−30.9***	−36.2***	−4.9**	−7.2*	−11.2*
	(5.3)	(7.9)	(10.3)	(2.2)	(4.1)	(6.1)
All middle income	−59.4***	−49.2***	−47.8***	−22.5**	−14.9**	−13.9**
	(20.1)	(12.5)	(13.8)	(9.1)	(6.2)	(5.9)
All high income	−151.7***	−142.8***	−115.0***	−57.1***	−49.2***	−33.5***
	(54.8)	(45.5)	(35.6)	(19.3)	(15.8)	(11.6)
Total population	−61.2***	−60.0***	−56.9***	−21.8***	−18.4***	−16.9***
	(15.4)	(13.4)	(13.0)	(6.0)	(5.5)	(5.6)
Unweighted	−71.6***	−71.6***	−71.6***	−20.6***	−20.6***	−20.6***
	(15.1)	(15.1)	(15.1)	(7.6)	(7.6)	(7.6)

Notes: Change in emissions from period 1 to period 4. Electric facilities are included. The number of observations ranges from 131 to 211.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Emissions Changes Across Neighborhoods.—Although average NO_x emissions at RECLAIM facilities fell by 70 percent between periods 1 and 4, this average could hide increases in emissions exposure in certain neighborhoods. Table 3 investigates how changes in emissions vary with demographics, as measured by the

1990 Census. We calculate the number of individuals N_{jd} in demographic group d living near RECLAIM facility j where near is defined by the fraction of the block group within a given distance from facility j. Let Δ_j represent facility j's observed change in emissions from period 1 to period 4. For each demographic group, we measure the average change in local emissions weighted by that group's population:

$$\frac{\sum_{j \in I_1} \Delta_j N_{jd}}{\sum_{j \in I_1} N_{jd}}. \tag{5}$$

These group-specific changes are reported in the left panel of Table 3. For all three distance measures (½, one, and two miles), we find that all groups experienced a reduction of emissions.[32] Within a half mile, high-income whites saw the largest actual reductions, while the group that saw the smallest reductions was low-income blacks. Over all races and ethnicities, high-income households experienced the largest reductions. Across all incomes, whites experienced the largest reductions in emissions. The exact magnitude of the results changes depending on the distance from facilities, but the findings are qualitatively similar.

In Section IV, we seek to isolate only those changes in emissions that are attributable to RECLAIM (vis-à-vis CAC regulation). The right panel of Table 3 previews these results. These adjusted changes are smaller for all groups because the control group also experienced a reduction in emissions over the study period. Most important, the relative emissions comparisons suggest that no group was exposed to more emissions due to emissions trading. It is still the case that the reduction in emissions experienced by some groups was smaller than for others. We will examine these results more closely in Section IVD.

IV. Results

In this section, we present our treatment effects estimates and conduct a series of robustness checks and falsification tests. We then test for heterogeneity in our treatment effect estimates and discuss selection issues.

Our outcome of interest is the change in facility-level annual NO_x emissions across different time periods. We report results generated using both levels and log transformed data. In the latter case, the SATT can be interpreted as our estimate of the average effect in percentage terms. Throughout, the control group is restricted to facilities located in counties that, like the RECLAIM counties, were not in attainment with the one-hour ozone NAAQS standards in 1990 and 1993.

Recall that 14 power producers were removed from the RECLAIM market in 2001 (period 3) but later reentered the market.[33] For a long-term view of the overall effectiveness of RECLAIM, we analyze changes in facility-level emissions between period

[32] Standard errors are computed by assuming the facility-level changes in emissions are i.i.d. One group did not have a statistically significant drop in emissions: the standard errors for high-income blacks are very large.

[33] One of these, Riverside Canal Power Company, is not in our complete dataset since it was decommissioned shortly after the electricity crisis due to the lack of environmental controls. (See http://www.energy.ca.gov/sitingcases/highgrove/documents/applicant/AFC_CD-ROM/Volume_01_AES_Highgrove_Project_AFC/8.13%20Waste %20Management.pdf).

Table 4—Average Treatment Effect using Nearest Neighbors Matching

	Levels	Logs	RECLAIM facilities	Controls
Panel A. Change in NO_x emissions between periods 1 and 4				
OLS	−32.58**	−0.30***	212	1,222
	(13.77)	(0.10)		
Nearest neighbor matching (base specification)	−20.59***	−0.25***	212	1,222
	(7.63)	(0.09)		
Nearest neighbor matching (alternative specification)	−18.12	−0.11	211	1,191
	(11.51)	(0.08)		
Nearest neighbor matching (restricted sample)	−14.16**	−0.20**	199	1,222
	(6.86)	(0.09)		
Panel B. Change in NO_x emissions between periods 2 and 3				
OLS	−6.84	−0.22***	255	1,577
	(6.65)	(0.04)		
Nearest neighbor matching (base specification)	−8.29**	−0.26***	255	1,577
	(3.85)	(0.06)		
Nearest neighbor matching (alternative specification)	−6.18	−0.16***	252	1,493
	(5.06)	(0.06)		
Nearest neighbor matching (unrestricted sample)	−6.37	−0.23***	268	1,577
	(4.57)	(0.06)		

Notes: We define periods as averages of positive emissions in two years: 1990 and 1993 (period 1); 1997–1998 (period 2); 2001–2002 (period 3); and 2004–2005 (period 4). All observations are from historic nonattainment counties. The OLS estimates control for average NO_x emissions during period 1 and four-digit SIC code indicator variables, with standard errors clustered by air basin. For all semiparametric matching, we match on the three closest neighbors with linear bias adjustment in levels and quadratic bias adjustment in logs. The baseline nearest neighbor matching model matches on historic emissions and exactly on four-digit SIC codes. In the alternative specification, industry-specific emissions quartile indicators are added to the exact matching variables; predetermined demographic characteristics (race and income) are added to the matching variables. Panel A's restricted sample omits 13 facilities removed from the program in 2001. Panel B's unrestricted sample includes these facilities. For the log specifications, emissions differences are defined as $\ln(\text{EmitX} + 1) - \ln(\text{Emit1} + 1)$, and all matching is on $\ln(\text{Emit1} + 1)$. Standard errors are reported in parentheses.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

1 and period 4. Our preferred approach uses data from all RECLAIM facilities to estimate this model. To estimate the effect of trading in RECLAIM during the crucial window surrounding the price spike, we analyze changes in facility-level emissions between period 2 and period 3. Here, our preferred specification excludes the 14 power producers since they were not part of the market during that time. We discuss below how including or excluding these facilities changes our results and their interpretation.

A. *Difference-in-Dfferences Estimates*

We first use a simple linear regression framework to generate conditional DID estimates. Facility-level emissions changes are regressed on industry fixed effects and NO_x emissions in period 1.

Panel A of Table 4 shows that the DID estimates of the RECLAIM program's impacts on long-run emissions changes are statistically significant at the 5 percent level. The levels estimate (−32.58 tons per year) is approximately 33 percent of the average annual emissions at RECLAIM facilities in period 1. Using the log-transformed data, the estimate is −0.30. Looking at changes in emissions over the cross-over period, estimated OLS treatment effects are also negative (panel B). However, in levels, we cannot reject the null hypothesis of zero effect. In all of these regressions, the period 1 NO_x coefficient (not reported) is statistically significant and negative in all specifications, indicating that historic emissions are a good predictor of emissions in later years.

B. *Semiparametric Matching*

The nonparametric nearest neighbor (NN) matching estimator constructs the counterfactual estimate for each treatment case using the control cases that most closely resemble the treatment cases.[34] If m nearest neighbors are selected for each program participant, the w_{jk} are set equal to $1/m$ for the selected neighbors and zero for all other members of the comparison group.[35] We impose a strict overlap condition; only those control facilities in the same industries as RECLAIM facilities are included in the pool of potential controls. We also require that all facilities be located in ozone nonattainment areas.

Following Abadie and Imbens (2006), we augment this nonparametric matching estimation with a regression-based bias adjustment so as to mitigate any bias introduced by poor match quality. After matching the treated facilities with m nearest neighbors, within-pair differences are adjusted using a parametric regression of the control outcome on $\mathbf{X}$.[36]

In all of our matching, we require an exact match on the four-digit standard industrial classification code. We prioritize industrial classification because these industry indicators are likely to be correlated with unobserved determinants of facility-level emissions including production technology characteristics, firm size, and demand for the products produced by the facility.

Our primary continuous matching variable is pretreatment (i.e., period 1) NO_x emissions. As we note above, historic NO_x emissions are a good predictor of emissions in subsequent periods. Our most parsimonious specification matches on attainment status, SIC code, and historic NO_x only. We refer to this as the base specification. We also experiment with matching on other observable factors that could conceivably be correlated with facility-level emissions trajectories such as the demographic and racial characteristics of the neighborhoods surrounding the

[34] Within the class of matching estimators, there are a variety of matching algorithms to choose from. Asymptotically, all matching estimators produce the same estimate. However, in finite samples, different matching estimators can yield very different treatment effect estimates, particularly if one or more of the identifying assumptions is violated. Alternative matching estimators are presented in online Appendix B.

[35] Although a larger m reduces the expected variance of the estimate because more information is used to construct the counterfactual for each participant, a large m also increases the bias of the estimate as the probability of making poorer matches increases. One drawback of this estimator is that all "neighbors" are equally weighted, regardless of their distance from the treated facility.

[36] More specifically, using data from matched control facilities, we regress the dependent variable (i.e., differences in emissions) on the covariates. We then use this regression model to impute counterfactual estimates for all treated facilities. Note that these estimates are not likely to be sensitive to our parametric assumptions because regression techniques are only used to impute differences in outcomes among very similar facilities. These bias adjustments are discussed in more detail in online Appendix B.

facility in 1990 and the size of the facility (as measured by number of employees). The larger the number of variables we use for matching, the less accurately we are to match on those variables for which we do not require exact matching. When we include additional matching covariates, we add an industry-specific emissions quartile indicator to the list of exact match variables.

Table 4 reports results for the base NN specification and one alternative specification that includes race and demographic matching variables in addition to historic emissions and industry classification.[37] Standard error estimates are constructed using the variance formula of Abadie and Imbens (2006). In each case, RECLAIM facilities are matched to their three nearest neighbors. Online Appendix Tables A2 and A3 demonstrate that our results are not overly sensitive to the choice of m or the bias adjustment.

For the overall change in emissions (panel A of Table 4), the NN estimate, -20.59 tons per year, is statistically significant at the 5 percent level. This represents 20 percent of the average annual emissions at RECLAIM facilities in period 1. Using log-transformed emissions data, the estimated coefficient is -0.25, implying that emissions reductions declined (in percentage terms) by approximately 25 percent more, on average, among RECLAIM facilities versus matched control facilities.[38] These estimated treatment effects are smaller (in absolute value) as compared with the OLS results. This suggests that differences in the distribution of covariates across the treatment and control group bias treatment effect estimates. When the 13 facilities that were removed from RECLAIM in 2001 are removed from the dataset, our SATT estimates remain statistically significant, although the point estimates are smaller in absolute value.

Making the period 2–period 3 comparison (panel B), the NN estimate is -8.29 and statistically significant at the 5 percent level. This represents a 12 percent reduction in the average period 2 emissions at RECLAIM facilities. The SATT estimate using log transformed data is 0.26. Notably, when we include in our sample the 13, major polluting facilities that were removed from the RECLAIM program in 2001, estimated level impacts fall and cease to be statistically significant. However, in the log specification, these large emitters are relatively less of an outlier: here the estimates are not significantly affected.

To summarize, these results indicate that emissions reported by facilities in the RECLAIM program fell by significantly more over the 15-year study period (i.e., 1990–2005) as compared to emissions reported by a group of California facilities located in nonattainment counties, operating in the same industries, with similar pre-RECLAIM emissions levels. When we narrow our focus to the window of time surrounding the cross-over point (i.e., the point at which the aggregate cap began to bind), we continue to find that emissions reductions among RECLAIM facilities are significantly greater on average as compared to the matched controls without the 13 power producers. When all facilities are included in the sample and the model is estimated using untransformed data, we can no longer reject the null hypothesis of zero difference

[37] Online Appendix B also summarizes results from additional matching exercises. Figure A2 reports the cumulative effects of the program for each year from 1995 through 2005.

[38] The estimated average annual reduction in the log specification is somewhat larger than the average reduction expressed as a percentage of period 1 emissions. This is consistent with percentage reductions being larger at smaller facilities.

Table 5—Indirect Test of Unconfoundedness

	Levels	Logs	Treated facilities	Controls
Panel A. Change in NO_x emissions between periods 1 and 4				
Nearest neighbor matching	−0.96	−0.07	265	554
(base specification)	(2.13)	(0.06)		
Nearest neighbor matching	3.01	−0.05	249	520
(alternative specification)	(2.49)	(0.07)		
Panel B. Change in NO_x emissions between periods 2 and 3				
Nearest neighbor matching	−0.35	0.08	434	642
(base specification)	(1.98)	(0.06)		
Nearest neighbor matching	0.02	0.01	394	547
(alternative specification)	(1.17)	(0.06)		

Notes: The treated facilities are redefined to be facilities in the South Coast Air Quality Management District that remained subject to CAC regulation on account of their low levels of emissions. See Table 4 for additional notes.

in emissions trajectories across RECLAIM and control facilities during this cross-over period. However, using log-transformed data, the treatment effect estimates remain highly significant over this cross-over period, with or without the 13 power producers.

C. *Evaluating the Underlying Assumptions*

In order to interpret these estimates as an unbiased measure of RECLAIM program impacts, some important assumptions must hold—in particular: conditional unconfoundedness and stable unit treatment values. Although these assumptions are not directly testable in principle, there are steps we can take to assess their plausibility.

Assessing Unconfoundedness.—First, our analysis assumes that the emissions trajectories of facilities in the control group are representative of the emissions trajectories that would have been observed at similar RECLAIM facilities had RECLAIM not been implemented. The weaker unconfoundedness assumption implies that $Y_{it'}(0)$ will be distributed similarly within subpopulations that are homogeneous in observable covariates. As we have two different control groups (i.e., facilities located within SCAQMD exempt from RECLAIM, and similar facilities located outside the SCAQMD), we can test whether the assumption holds across these two groups. The key to this test is that these two control groups are likely to have different biases. The emissions trends at facilities outside of SCAQMD may differ from the counterfactual trends of matched treated facilities because they are operating in different counties and are regulated by different regional agencies. In contrast, the emissions trends at smaller facilities in the SCAQMD may differ from the counterfactual trends of matched treated facilities because they have lower baseline emissions.

To conduct the test, we redefine our "treated" group to be facilities in the SCAQMD but not regulated by RECLAIM. Our pool of control facilities consists of facilities located in nonattainment areas other than the South Coast. If unconfoundedness holds for these two groups, the estimated "pseudo" treatment effects should not be statistically distinguishable from zero.

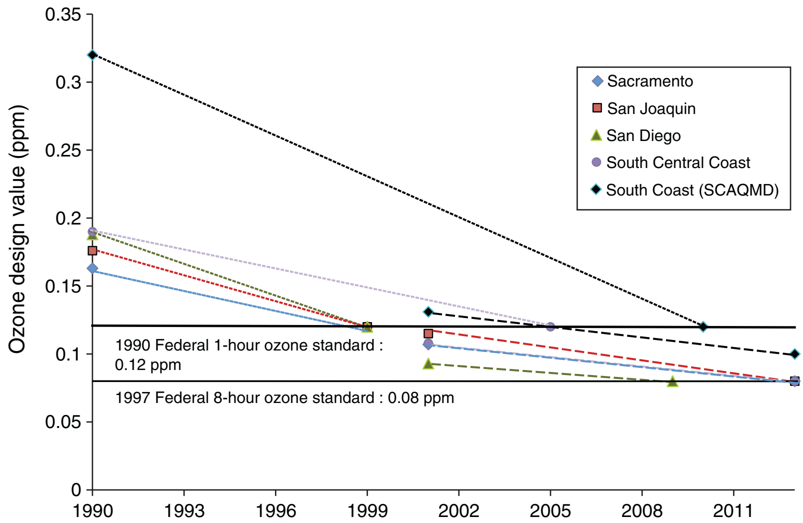

Figure 3. Required Ozone Concentration Reductions for Five Californian Air Basins

Notes: This figure illustrates the ozone concentration reductions required of the five California air basins with the most severe air quality problems. Dotted lines connect an area's 1990 "design value" with the federal one-hour ozone standard in the year the basin is required to achieve compliance. A design value is an air quality measurement that is used to determine an area's air quality status (in reference to a National Ambient Air Quality Standard). Areas that had relatively high ozone concentrations in 1990 (and high design values) were given more time to come into attainment with the federal standard. Compliance deadlines were established under the CAAA 1990. In 1997, the EPA issued a federal eight-hour standard of 0.08 ppm. This standard was officially upheld by the courts in 2001. The broken lines connect an area's eight-hour design standard (measured in 2001) and the federal eight-hour standard in the year the area must comply with this standard. Deadlines for compliance with the eight-hour standard can be found at http://www.epa.gov/ozonedesignations/regions/region9desig.htm. Historical data on ozone design values are available from California Air Resources Board: http://www.arb.ca.gov/adam/php_files/aqdphp/sc8start.php.

Table 5 summarizes the results from this experiment. We find that the change in the average emissions (in levels or logs) among these facilities located in SCAQMD that remained subject to more prescriptive forms of emissions regulation is not statistically different from that of the control group. Put differently, the emissions trajectories among smaller SCAQMD facilities exempt from RECLAIM and the emissions at observably similar facilities located in other California air basins follow similar paths. These results are consistent with the weak unconfoundedness condition upon which our estimation is predicated.

The stronger unconfoundedness assumption requires that the control regulations mimic the changes in the stringency of regulations that RECLAIM facilities would have been subjected to had RECLAIM not been introduced. To assess the plausibility of this assumption (albeit crudely) we look at the ozone concentrations reductions mandated in SCAQMD vis-à-vis other California air basins over the study period.

Figure 3 illustrates the compliance requirements required under the CAAA for five air basins in California. The dotted lines connect one-hour ozone concentration values in 1990 (when the CAAAs were passed) with the federal one-hour standard (0.12 ppm) in the year in which the air basin was required, under the auspices of the

Table 6—Robustness to Control Group Using Nearest Neighbor Matching

Control group	Levels	Logs	RECLAIM facilities	Controls
Panel A. Change in NO_x emissions between periods 1 and 4				
Base specification	−20.59***	−0.25***	212	1,222
	(7.63)	(0.09)		
Exclude L.A. facilities	−23.50***	−0.34***	210	778
	(7.96)	(0.09)		
Exclude northern CA	−26.60***	−0.23**	210	767
	(7.58)	(0.11)		
Severe nonattainment only	−21.65**	−0.29**	208	475
	(7.89)	(0.11)		
Single facility only	−19.92**	−0.23**	210	781
	(7.60)	(0.10)		
Panel B. Change in NO_x between periods 2 and 3				
Base specification	−8.29**	−0.26***	255	1,577
	(3.85)	(0.06)		
Exclude L.A. facilities	−8.49*	−0.21***	247	877
	(4.40)	(0.07)		
Exclude northern CA	−14.24***	−0.28***	255	1,090
	(3.90)	(0.07)		
Severe nonattainment only	−13.14***	−0.17**	244	541
	(4.01)	(0.07)		
Single facility only	−14.99***	−0.21***	253	1,027
	(4.67)	(0.06)		

Notes: Panels report results for the base specifications. See Table 4 for notes.

CAAA, to come into compliance.[39] The broken lines represent the more recently required ozone concentration reduction trajectories that pertain to the federal eight-hour ozone standard.[40] The black lines (associated with the highest ozone concentrations) correspond to the SCAQMD. Because SCAQMD was much further from attainment as compared to other air basins, the district was given more time to comply. Although ozone concentrations (and thus the extent of nonattainment) in the South Coast significantly exceed those of other California nonattainment areas, mandated reductions follow similar—if not parallel—trajectories over time. This figure helps to illustrate how mandated ozone concentration reduction trajectories were similar across California's nonattainment counties. This is consistent with our assumption that changes in the stringency of regulations affecting industrial sources of NO_x emissions in SCAQMD and other nonattainment areas would have followed similar paths had RECLAIM not been introduced.

[39] Under Title I of the 1990 CAAAs, requirements for the 96 metropolitan areas failing to attain federal ozone standards were significantly revised. Nonattainment areas were reclassified according to the extent to which they exceeded federal standards. Each classification was subject to a different deadline for achieving compliance.

[40] In 1997, the EPA concluded that the one-hour standard was inadequate for protecting public health. The Agency issued a federal eight-hour standard of 0.08 ppm which was officially upheld by the courts in 2001. Deadlines for compliance with the eight-hour standard can be found at http://www.epa.gov/ozonedesignations/regions/region9desig.htm.

Assessing the Stability of Unit Treatment Values.—Our analysis also assumes that the treatment received by one facility does not affect emissions at other facilities. If the introduction of the RECLAIM program caused production and associated emissions to shift from RECLAIM facilities to those exempt from the program, this would bias our counterfactual emissions estimates and exaggerate our estimates of program impacts.

Violations of this assumption are empirically intractable unless we generate some specific hypotheses regarding how these violations would manifest. We test three such hypotheses using different subsets of the control group to identify the sample average treatment effect. First, if the introduction of RECLAIM caused production to shift to control facilities, and if this shift disproportionately affected control facilities in proximity, we would expect to find larger treatment effects when the control group is restricted to nearby facilities. The first row of results in Table 6 shows that dropping the closest facilities in the control group (i.e., those located within the SCAQMD) does not significantly affect the results. The second row excludes the facilities farthest away (i.e., northern California facilities) from the control group. This also has no significant impact on the results.

Second, if RECLAIM induced shifts in production were more likely to occur in relatively less stringently regulated regions where the limits imposed by CAC regulation are more lax, we would expect to find smaller treatment effects when the control group is restricted in this way. We restrict the control group to those facilities located in *severe* nonattainment counties. The third row of results in Table 6 reports SATT estimates obtained using only data from facilities in severe (versus moderate) nonattainment areas as controls. Estimated program effects are not significantly impacted.

Finally, if moving production (and thus emissions) from one facility to another is more easily coordinated within a firm versus across firms, RECLAIM induced shifts in production will be more likely to occur within a parent company with facilities inside and outside of RECLAIM (versus across facilities that do not share a common owner). In this case, we would expect to find smaller treatment effects when the control group is restricted to single plant firms. The final row of results in Table 6 shows that our results are robust to this restriction.

D. *Heterogeneous Treatment Effects*

Next, we ask whether the reduction in emissions that occurred under RECLAIM, in comparison to those in the control group, are correlated with demographics. In particular, we ask whether traditionally disadvantaged neighborhoods in the SCAQMD experienced similar emission reductions as compared with other neighborhoods.

Table 7 summarizes the results of estimating equation (4).[41] Estimation of the θ parameters in (4) facilitates a test of whether the treatment effect is heterogeneous with respect to historic emissions, income, and percent minority. We estimate each effect separately as well as jointly. Panel A of Table 7 presents the results where the dependent variable is the change in the level of emissions from periods 1 to 4 for the

[41] Results using the log transformed values are reported in online Appendix Table A6.

Table 7—Environmental Justice Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Change in NO_x emissions between periods 1 and 4							
Treatment	−20.64**	−20.38*	−17.49**	−20.46**	−18.52**	−15.26***	−17.71**
	(7.81)	(8.85)	(6.17)	(7.41)	(7.04)	(4.36)	(5.29)
Treat × Period 1 NO_x	−0.19			−0.19	−0.19		−0.18
	(0.11)			(0.11)	(0.11)		(0.11)
Treat × income		−1.27		−0.65		0.42	−0.02
		(0.96)		(1.09)		(1.95)	(1.53)
Treat × %Minority			0.94		0.43	1.04	0.41
			(0.60)		(0.36)	(0.96)	(0.51)
Period 1 NO_x	−0.48***	−0.49**	−0.49**	−0.48***	−0.48***	−0.49**	−0.48***
	(0.11)	(0.15)	(0.15)	(0.11)	(0.11)	(0.14)	(0.11)
Income		0.10		0.16		−0.66	−0.24
		(0.80)		(0.74)		(1.47)	(1.04)
%Minority			−0.35		−0.22	−0.52	−0.28
			(0.31)		(0.26)	(0.56)	(0.37)
R^2	0.87	0.85	0.85	0.87	0.87	0.85	0.87
Panel B. Change in NO_x between periods 2 and 3							
Treatment	−6.70***	−7.19**	−6.29***	−7.16***	−6.62***	−6.45***	−7.05***
	(1.43)	(2.22)	(1.35)	(1.45)	(1.25)	(1.85)	(1.23)
Treat × Period 1 NO_x	−0.06***			−0.07***	−0.07***		−0.07**
	(0.02)			(0.02)	(0.02)		(0.02)
Treat × income		−0.16		−0.09		−0.12	−0.22
		(0.24)		(0.17)		(0.36)	(0.35)
Treat × %Minority			0.09*		−0.004	0.05	−0.07
			(0.04)		(0.045)	(0.11)	(0.14)
Period 1 NO_x	−0.35***	−0.34***	−0.34***	−0.34***	−0.34***	−0.34***	−0.34***
	(0.08)	(0.05)	(0.05)	(0.08)	(0.08)	(0.06)	(0.08)
Income		0.19		0.16		0.05	0.15
		(0.36)		(0.33)		(0.47)	(0.46)
%Minority			−0.11		−0.05	−0.10	−0.02
			(0.07)		(0.06)	(0.11)	(0.11)
R^2	0.52	0.47	0.47	0.49	0.49	0.47	0.49

Notes: Panels report results for the base specifications. For regressions with 1990 demographic data, there are 875 and 1,043 observations in panels A and B, respectively. Group fixed effects are not shown. Treated observations receive a weight of one and control observations receive a weight of $1/m_j$, where m_j is the size of the control group for treated facility *j*. %Minority is percent of population that is black or Hispanic. See Table 4 for additional notes.

full sample. In panel B, the dependent variable is the change in the level of emissions from periods 2 to 3 for the restricted dataset that focuses on those facilities that were participating in (and complying with) the cap-and-trade program during this period. We do find that RECLAIM facilities polluting more in period 1 reduced emissions more during this time period. However, we do not find evidence of 1990 demographics being a significant determinant of which facilities reduced emissions.[42]

In all specifications, the *Period* 1 NO_x coefficient is statistically significant. Ideally, our within-group matching on historic NO_x emissions would be perfect and

[42] We have also estimated these models using the restricted sample for the change in emissions from periods 1 to 4, and for the full sample from periods 2 to 3. The models have also been estimated using 2000 census data, as well as using a log specification. See online Appendix B for a discussion of these results.

the *Period* 1 NO_x coefficient would not be identified. In fact, our data are not sufficiently rich to facilitate perfect matching; historic emissions do vary within a group of matched facilities. Moreover, we find that this within-group variation in historic emissions is significantly correlated with the dependent variable. These results serve to highlight our concerns about the bias potentially introduced by poor match quality. All of our matching estimation incorporates a parametric adjustment to mitigate this bias (Abadie and Imbens 2006).[43]

In panel B of Table 7, the variable *Treat* × *Period* 1 NO_x is statistically significant, indicating larger emissions reductions at larger facilities. Online Appendix Figure A3 helps to illustrate this relationship between changes in emissions and historic emissions both for RECLAIM and for other facilities in more detail.[44] We smooth the observations, separately for RECLAIM and for other facilities, using a *k*-Nearest Neighbor estimator. We see that the relationship between historic emissions and change in emissions is decreasing over the range of zero to 80 tons per year of historic emissions. In contrast, the control group is relatively flat at zero for most of the range: from zero to 55 tons that accounts for over 80 percent of the sample.

Thus far, our analysis has focused on average correlations between the relative impacts of RECLAIM on facility-level emissions trajectories and neighborhood characteristics. We might also be interested in the distribution around the mean and, in particular, investigating whether *any* neighborhoods were exposed to more emissions under RECLAIM vis-à-vis the CAC counterfactual. Figure 4 illustrates the geographic distribution of emissions under RECLAIM and the CAC counterfactual, respectively. We compute the fraction of each block group that is within two miles of each RECLAIM facility and then use these fractions to assign emissions to each block group. Panel A of Figure 4 shows the RECLAIM emissions assigned to each block group by this procedure, and panel B shows the counterfactual emissions assigned to each block group. Note that if two facilities are located within two miles of a block group, emissions from both facilities are assigned to the block group.[45]

Panel A of Figure 4 shows that there is spatial clustering of the emissions permitted under RECLAIM. However, panel B illustrates similar spatial patterns of emissions implied by the CAC counterfactual. The preceding analysis has demonstrated that, on average, facility-level emissions are lower under RECLAIM as compared to the CAC counterfactual. Figure 4 shows that these relative reductions are distributed across the entire SCAQMD jurisdiction. This evidence suggests that RECLAIM did not contribute to hotspots.

Our results suggest that some neighborhoods were exposed to higher levels of emissions under RECLAIM. Figure A4 in the online Appendix identifies these neighborhoods explicitly. Using a similar approach, we construct changes in NO_x emissions (i.e., observed emissions less the CAC counterfactual emissions) by block group. A very small subset of affected block groups did see a relative increase in emissions at

[43] Online Appendix Table A2 shows that our results are not highly sensitive to this bias adjustment.

[44] For each treated observation, we construct a measure of what the change in emissions would have been for the control group if the control group had the same historic emissions as the treated observation. This is done by using bias adjustments developed by Abadie and Imbens (2006) to mitigate bias introduced by poor match quality. We use a quadratic fit (see online Appendix Table A2).

[45] This procedure is equivalent to a crude pollution transport model with transfer coefficients equal to the fraction of the block group area located within two miles of the facility.

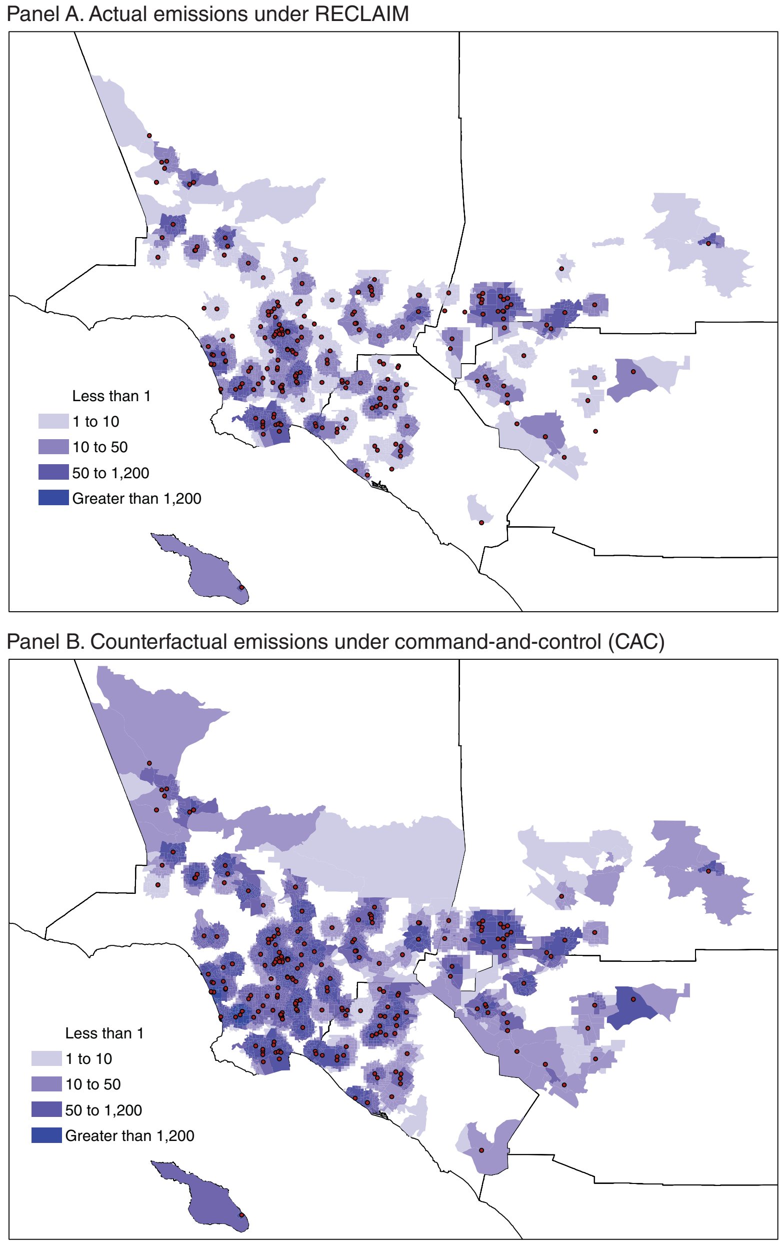

Figure 4. Actual Emissions under RECLAIM and Counterfactual, Command and Control Emissions in Tons of Nitrogen Oxides in Period 4

facilities within two miles. Almost all affected block groups had a net reduction in emissions from RECLAIM.[46]

[46] The small subset of block groups that are exposed to higher emissions levels under the RECLAIM regime as compared to the CAC counterfactual comprises fewer minority and low income households as compared to the average block. Overall, these households are 34 percent white (versus an average of 30 percent); average household income is \$52,000 versus the average \$47,000.

E. *Selection Issues*

Section III describes the unbalanced nature of our panel. Nonrandom selection into and out of our balanced panel could introduce selection bias. The direction of this bias, were it present, is unclear. One might be concerned that facilities with relatively high abatement costs would be more likely to exit a CAC regime that offers less compliance flexibility. This would result in inflated estimates of RECLAIM program impacts vis-à-vis the CAC counterfactual. On the other hand, if a market-based approach makes more stringent emissions reductions politically feasible, RECLAIM facilities with relatively high abatement costs might exit with higher frequency, thus biasing our results in the opposite direction.

Online Appendix B attempts to assess selection bias by estimating a Heckman (1979) selection model, analyzing patterns of entry and exit, and imputing missing emissions.

V. Conclusions

In this paper, we exploit some unique design features of the RECLAIM program in order to bring new evidence to bear on two important questions. First, did emissions reductions at facilities subject to Southern California's RECLAIM program exceed emissions reductions achieved at very similar facilities subject to CAC regulation over the same time period? Second, has the compliance flexibility afforded by market-based environmental regulation resulted in more (or less) pollution in traditionally disadvantaged communities?

Our results indicate that emissions at RECLAIM facilities fell approximately 20 percent, on average, relative to the control facilities over the first ten years of the program. These results are robust to alternative matching strategies. During the period of great permit price volatility, the results are more nuanced. During this period, 14 power producers were removed from the program. When these facilities are excluded from the analysis, we find strong evidence that emissions among RECLAIM facilities fell relative to very similar control facilities. However, when all facilities are included in our analysis of emissions trends during this volatile time, the evidence is weaker.

We find no evidence that the estimated relative effects of RECLAIM on facility-level emissions vary systematically with neighborhood demographic characteristics. In particular, we find no correlation between our estimated effects and neighborhood measures of income or percent minority. We conclude that no racial or income group experienced a significant increase in emissions due to RECLAIM.

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